Brazed and welded cans for transport and storage of damaged fuel rods

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Abstract

For the type B(U)F package NCS 45 helium tight cans are stipulated in the certificate of package approval to provide a barrier for the radioactive material under routine and normal conditions when transporting fuel rods with a burn-up of more than 62 GWd/MgHM. For damaged fuel rods a significantly higher mass of heavy metal is permissible when using welded or brazed cans.

In the first part of the presentation, the qualification process for the fabrication of brazed/welded cans is described. In the second part of this presentation the operation of the DAHER Underwater Brazing Equipment and the preparation required for such operation in a nuclear power plant are shown. This includes also the necessary steps for qualification at the manufacturer site.

For the encapsulation underwater in a NPP pool site-specific step by step handling instructions must be established, reviewed by the NPP operators for compliance with the NPP operation and checked and released by the responsible independent expert assign by the Supervising Authority for such purpose. Site-specific adaptations of the support frame must be reviewed, checked and released, too.

For the production of brazed cans in a NPP pool as well as for the production of welded cans in a Hot-Cell specific specifications, procedures and checklists for brazing/welding and QA-measures before and after encapsulation must be released by the Competent Authority responsible for the certificate of package approval before operation.

The presentation will give an overview about the required documentation, show results of already completed encapsulation campaigns.

Introduction

The package NCS 45 is licensed for the transport of fuel rods with a burn-up of up to 120 GWd/MgHM. Fuel rods with a burn-up of more than 62 GWd/MgHM must be encapsulated. The cans must not contain free water and must be sealed by welding or an adequate method.

The production of welded cans inside Hot Cells is common practice but there is no comparable method for fuel rods stored under water, where welding is not applicable and/or is not a reliable solution. In order to overcome this problem DAHER has developed and patented a solution to produce, using the brazing method, sealed and dry cans containing fuel rods.

This presentation will provide first an overview on the QA requirements (safety analysis report, specification, MTSPs, destructive and non-destructive controls…) on the can and its own components, present the different control measures required for the process qualification, the associated encapsulation process and will conclude with a description of site-specific requirements for implementing brazing encapsulation equipment.

Quality Assurance Requirements

As the BAM (Federal Institute for Materials Research and Testing) is the competent safety authority for approval and monitoring of QA measures on type B(U)F NCS 45 package and the cans are stipulated in its certificate of package approval, each component of the cans has been classified according to BAM-GGR 011 Guideline "*Quality Assurance Measures of Packagings for Competent Authority Approved Package Designs for the Transport of Radioactive Material*". The cladding tube, the upper and lower plugs as well as welding or brazing connections belong all to the "Grade 1", which is the highest and more stringent grade of the safety classification, because they ensure immediately the safety objectives in terms of shielding (radiation protection), containment and prevention of criticality.

In addition, the guideline stresses that the applicant/approval certificate holder is responsible for the determination of quality assurance measures during design, construction, manufacturing and operations with the package and its internals (can, transport basket).

General Design Requirements for welded and brazed can

The safety proof for the different designs of cans is carried out in the Safety Analysis Report of type B(U)F NCS 45 package.

The following requirements apply for both cans:

- designed to withstand routine, normal and accidental conditions of transport as specified in the Regulations,
- provide a leak tight barrier for the fuel under normal conditions of transport,
- corrosion resistance under the conditions to be expected in the reactor pool,
- cavity of the can filled with inert gas (e.g. Helium),
- to prove the mechanical properties of the brazed or welded connections pressure tests are required.
- designed to be handled in NPPs and Hot Cells (e.g. German KTA requirements).

In chapter 4 of the NCS 45 package' safety analysis report the mechanical analysis of the can is carried out, with conservative assumptions, in accident conditions of transport (acceleration of the content: 350 g in vertical drop and 100 g in horizontal drop).

- In case of a horizontal drop from 9 m height of the packaging, in which a can is loaded in a transport basket, it is ensured that the resulting stress on the upper part of the can which sticks out (the grip), is lower than the yield stress of stainless steel or zircalloy or brazing solder at the same accident temperature conditions.

- The vertical drop from 9 m height onto the top head side of the packaging is unproblematic for the top plug, because of its contact with the packaging. The force applied by the fuel rod and the tube onto the top plug does not affect the mechanical property of the seam.
- During the vertical drop from 9 m height to the bottom side of the packaging, in which a can is loaded in a transport basket, only the weight of the bottom plug and the weight of the fuel rod act on the connection point of the bottom plug. The resulting shear stress on the seam is lower than the yield stress of stainless steel or zircalloy or brazing solder.
  When considering the resulting force of 28.9 kN for a vertical drop at the bottom side of the brazing can (350 g acceleration) the minimal acceptable length of the brazing is **2.6 mm** according to the strength analysis.

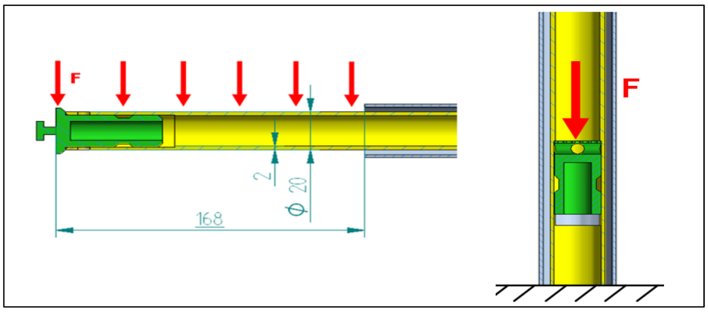

Figure 1: Drop configurations in accidental conditions

The current application requires cans which could withstand normal conditions of transport but the safe design of brazed/welding cans withstand also accidental conditions of transport.

Design of the brazing can

Brazing transport cans are foreseen for dry loading in a hot cell but mainly for wet loading in a pool by using an underwater brazing equipment.

The main body is a tube (1) made of stainless steel. On the top side the tube has two holes (10) which allow safe handling of the empty tube under water. On the bottom side the tube has two slits (5) through which the water is drained after the fuel rod was loaded. The tube is closed on both sides with two plugs which are connected to the tube by brazing. The bottom plug (3) is preassembled with the tube. In the "loading" position the bottom plug allows draining of the water through a filter (4) in the plug and the corresponding slits in the bottom part of the tube. In order to reach the "brazing" position the bottom plug is pushed axially into the tube and comes to rest above the slits. The top plug (2) is inserted after loading of the fuel rod into the can and is positioned by a circular stop (6). The outer shape (7) of the top plug can be adapted to the requirements of the nuclear site to allow handling with existing tools. Both plugs are made of stainless steel. The brazing solder is fixed to the plugs in a deposit (8) which is applied by using the "cold gas spray" technology. During the brazing operation the brazing solder becomes liquid and flows into the narrow gap (9) between the tube and the plugs and seals these connections.

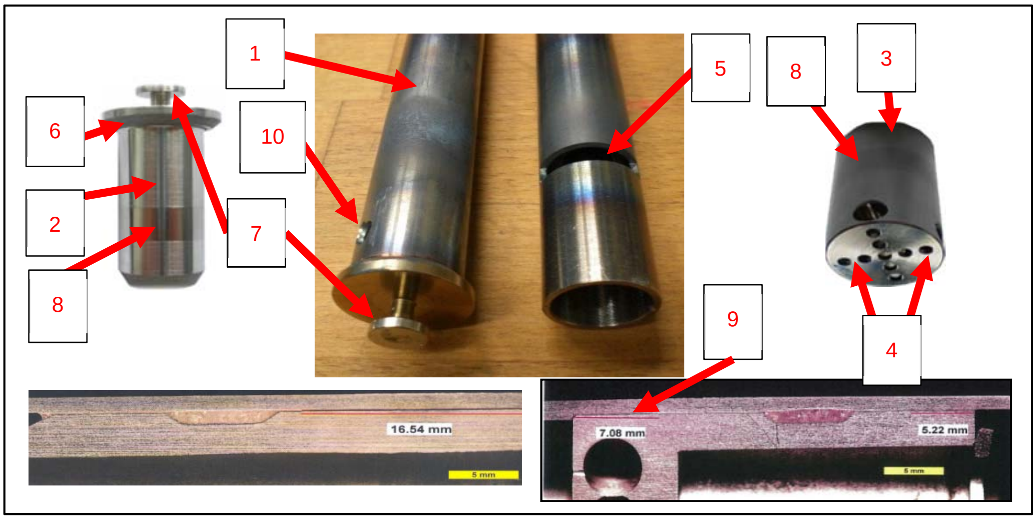

Figure 2: Brazing can description

<u>Design of the welding can</u>

Welding transport cans are foreseen for dry loading in a hot cell.

The main body is a tube (1) made of stainless steel. As this tube will only be handle in horizontal position in a hot cell with a remote handling (tele-manipulator) no specific handling holes are required. No slits are required at the bottom of the tube as the encapsulation will be done in dry conditions. As general rule the bottom plug (2) is welded with the cladding tube before one or more segments of fuel rods are loaded into the can. Eventually the top plug (3) is inserted into the can and is first welded on its circumference before its extremity will be closed. The opening (4) at the extremity of the top plug allows the heat evacuation when performing the orbital welding and the filling of the can with helium. The outer shape (5) of the top plug can be adapted to the requirements of the nuclear site to allow handling with existing tools.

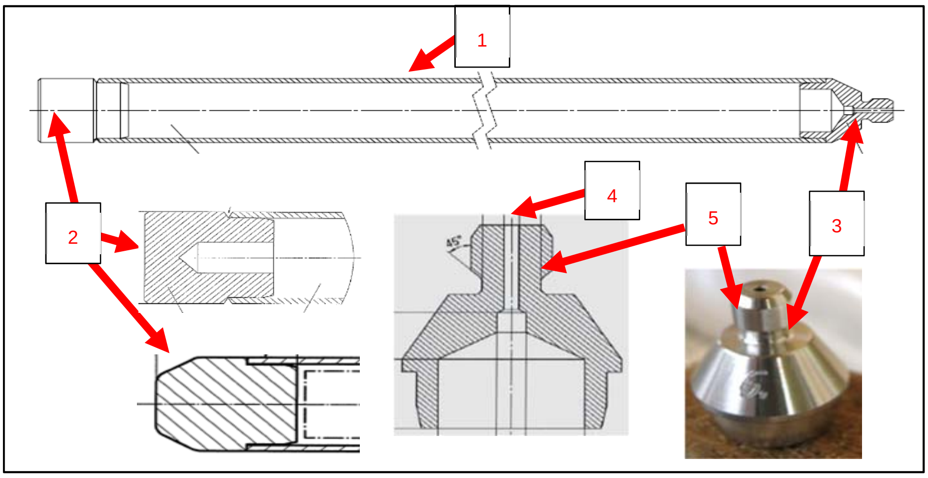

Figure 3: Welding cans description

Manufacturing

The fabrication of the cans is carried out, with control of the approval certificate holder, in two steps and if necessary by two different manufacturers:

- The single parts of the cans are prefabricated and delivered to the storage place of the fuel rods; the manufacturer n°1 is qualified according to the manufacturing specification, which has been established by DAHER and then released by BAM.
- At the storage place of the fuel rods these are loaded into the cans and the cans are closed; the manufacturer n°2 (Hot Laboratories for welding cans and DAHER for brazing cans) is qualified according to the manufacturing specification which has been established by DAHER and then released by BAM and based on site specific conditions

Each manufacturer is responsible for the preparation of the manufacturing and test sequence plan including related working and testing instructions, welding plans, material testing plans and if applicable further documents for manufacturing. These pre-assessment of these documents is carried out first by the certificate approval holder and eventually by the competent authority or its external expert prior starting with the manufacturing.

In Germany, for the "Grade 1" components their manufacturing has to be monitored by the certificate approval holder in combination with BAM or its authorized inspection expert.

The manufacturer who fabricates the semi-finished or the finished products solder is responsible for:

- Presentation of a Quality Management Manual (QMM) and the certification according to ISO 9001 in applicable revision.
- Preparation of manufacturing and test sequence plans (MTSP) according to DAHER requirements.
- Welding process and welding operators qualification.
- Preparation of welding drawings and plans.
- Preparation of material lists according to DAHER standard form.
- Provision of the pre-qualification documents, first, at DAHER for approval and then at BAM for approval.
- Implementation and performance of the quality assurance program.
- Correct procurement of e.g. materials and auxiliary means.
- Qualification of fabrication processes, if required.
- Fabrication and assembling.
- Supervision e.g. of purchased parts and fabrication processes.
- Compliance with valid regulations, standards and directives.
- Preparation of deviation reports (if required) after clearance with DAHER.

- Preparation of test procedures if not provided by DAHER.
- Preparation of the documentation.

DAHER is responsible for:

- Presentation of a Quality Management Manual (QMM) and the certification according to ISO 9001 in applicable revision.
- The selection of the manufacturer (Qualification), Auditing of the QM system of the manufacturer.
- Observance of requirements of nuclear technology.
- Brazing personnel certification.
- Design of the cans and proof of safety.
- Selection, control, check and documentation of manufacturer of semi-finished products and welding cans.
- Preparation of QA documents (Material specifications, Material test sheets, Manufacturing test plan for brazing cans).
- Implementation and performance of the quality assurance program.
- Modification/update of the specification if required.
- Certification of final acceptance.
- Approval procedure at BfS/BAM.

After manufacturing of the can the manufacturer has to complete the documentation and has to submit it to DAHER for checking and then to BAM expert for approval.

Process Qualification:

To qualify the different procedures prototype cans without radioactive content have to be manufactured and tested destructive or non-destructive according to DAHER established specification, which has been released by the BAM.
The process qualification comprised the entire process from loading, draining, drying and brazing to Helium leak test. Before use of a certain type of a can (welded or brazed) generally at least 3 prototype cans with dummy content according to the established specification and the manufacturing documentation have to be produced. These prototype cans have to be manufactured under the same environmental conditions as the planned loading with fuel rods.
The following non-destructive tests have to be carried out:

- visual check of welds or brazed seams,
- helium leakage test,
- only for the process qualification:
    - surface crack test of welds or brazed seams,
    - metallographic analysis need to be carried out to investigate the influence of the heating on the structural properties of the seams,

- pressure test.

Results of all the non-destructive and destructive tests have to be documented in a report, which has to be approved and released by the competent safety authority.

Requirements for the encapsulation process

Requirements for the brazing encapsulation process

The encapsulation process must meet the following requirements:

- the production installation must be designed to be operated in the fuel storage pool,
- easy and safe loading of cans and fuel under a sufficient head of water,
- remote controlled brazing,
- high quality parameters process control,
- documentation of process parameters.

The encapsulation process consists of following general steps:

1° Loading of can and fuel rod, closing of the encapsulation device

Prior to loading, the lid of the encapsulation device is opened. The empty can with preassembled bottom plug is attached to the handling tool and lowered into the device. Then the fuel rod is inserted into the empty can by using the fuel rod handling tool of the nuclear site. Insert upper plug. After that the upper plug has to be put in the UBE.

2° Draining and drying, filling with Helium

The water inside the cavity of the encapsulation device and the can is drained via the connections. The water inside the can drains through the holes in the bottom plug and the slits in the tube. Then, the cavity of the encapsulation chamber and the cavity of the can are dried by means of vacuum drying. After reaching the drying criterion, the cavity of the encapsulation device together with the cavity of the can are filled with Helium.

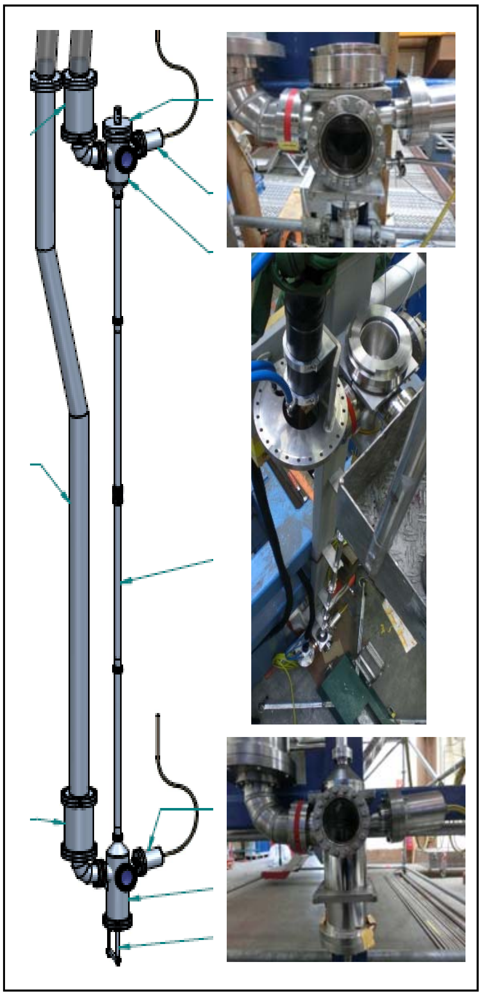

Figure 4: UBE Chamber

3° Brazing

Before brazing starts, both plugs are lifted into the brazing position by using a mechanical system that can be operated by a person standing outside the pool. Additionally the correct position is controlled by underwater cameras through windows in the UBE. The brazing solder is then heated up by inductive heating until it becomes fluid and flows into the gap between tube and plug.

4° Flooding of the encapsulation chamber and removal of the sealed can

The encapsulation chamber is then flooded with water via the connectors, opened and the sealed can is removed with the handling tool and transferred into the leak test station (see figure 5).

5° Helium Leakage test

After draining and drying of the leak test chamber, the helium leak tightness is measured thanks to a Helium Leak detector connected to the chamber. The test chamber is eventually flooded with water via the connectors, opened and the can is removed with the handling tool and transfer into a transport basket.

Figure 5: Leak test station

Requirements for the welding encapsulation process

The welding encapsulation process must meet the following requirements:

- to be operated in dry conditions in hotcells,
- easy and safe handling of cans under a sufficient head of water,
- high quality process control,
- remote handling conditions,
- documentation of process parameters,
- to get the smallest as possible overlap welding on the welded areas in order to easily and safely positioned the welded can inside the transport basket tube and, if required, to position it after in a storage pool.

1° Welding the bottom plug with the cladding tube

During the first campaign of encapsulation in 2014 WIG (Wolfram-Inert-Gas) Welding process has been applied to weld the bottom plug on cladding tube. Here, the arc burns between a non-consumable wolfram electrode, a filler and the work piece. The electrode, the arc, the filler and the weld pool are shielded against the atmosphere by an inert gas.

Then the leak tightness of bottom plug's welding joint is controlled thanks to a Helium leak detector.

2° Loading of can and welding of top plug

After having transferred the cladding tube (bottom plug already welded) and the top plug to be welded inside the Hot-Cell, the tube will be loaded with one or several segments of fuel rod; if required some spacers could be mounted too. Then the top plug is positioned and welded first on its circumference thanks to orbital fusion welding technic (see Figure 6).

Orbital welding is a mechanized version of the tungsten inert gas arc welding (TIG) process and is used to weld stationary tube or pipe; the tungsten electrode contained in the weld head rotor rotates or "orbits" around the weld joint circumference. The TIG process applied was the fusion (autogenous) process in which the edges of the weld joint are heated by the arc and fused together without the addition of filler material to the weld pool; in that sense no overlap welding is present.

Eventually the extremity of the top plug, used to evacuate the heat from the circumferential welding and filling with helium, will be closed thanks to the spot welding technic (see Figure 9).

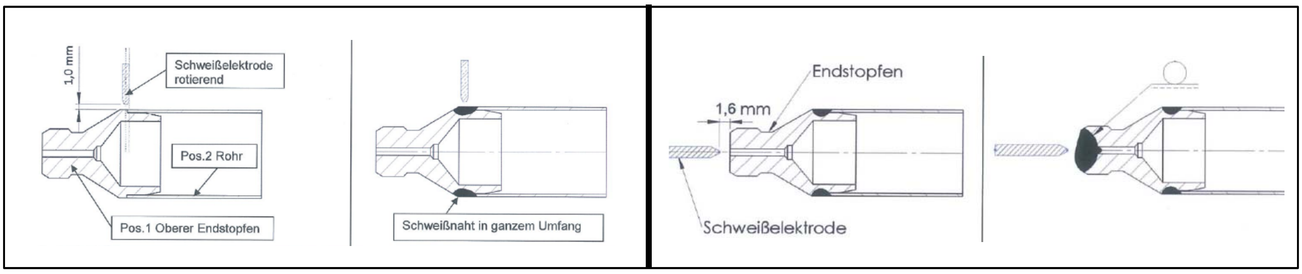

Figure 6: Circumferential and Spot weldings

For sure, it makes more sense to apply for the next encapsulation campaign the orbital fusion welding technic on the bottom plug too in order to avoid any overlap on welded area and to insure high quality repeatable welding. Eventually the leak tightness of the welded seam on the top plug is controlled thanks to a helium leak detector. The helium leakage should be smaller than $1x10^{-7}$ $Pa.m^3.s^{-1}$.

Site-specific Requirements

The design of the UBE allows very flexible, easy and different ways how to place it in the pool of a nuclear facility. One solution already developed consists in fixing the UBE on the balustrade of the pool with a frame. The second solution was developed for a nuclear power plant in Germany. Here the UBE is fixed on a rack, which has four independent feet to allow the adjustment in case of unevenness of the floor and is designed to fulfill the KTA standards and the earthquake vibration (see Figure 7).

Figure 7: UBE in standing rack

Conclusions

The encapsulation process comprising the manufacturing of high and stringent grade of safety components, the encapsulation device, proper working and testing instructions, manufacturing sequence plans and QA measures requires first the competent safety authority's acceptance thanks to a pre-assessment of documentation, manufacturing inspection and different qualification tests.

In fact the brazed or welded cans ensure the same safety objectives as fuel rods (cladding with fuel pellets) in terms of shielding (radiation protection), containment and prevention of criticality on the content to be transported and stored for intermediate or long terms

Eventually DAHER encapsulation equipment fulfills the NPP's high requirements regarding handling and operations in fuel storage pools while keeping enough flexibility to adapt it to any NPP.

References

1. **Breuer, Thomas.** Qualification of the DAHER-NCS Fuel Rod Encapsulation Process for Transport and Storage. *PATRAM 2013.*

2. **Stanke, Simon.** Encapsulation of Fuel Rods for Transport. *PATRAM 2010.*